BIVALVES

GIANT CLAMS (Family Tridacnidae)

Giant clams have played a major role in islander life for thousands of years. There are nine species in two genera—*Tridacna* and *Hippopus*—in the family Tridacnidae. The confused taxonomy of these species was revised by Rosewater (1965) and recently reviewed by Lucas (1988). Since Rosewater's 1965 revision, *Tridacna tevoroa* and *T. rosewateri* have been described by Lucas et al. (1990, 1991) and Sirenko and Scarlato (1990), respectively; *Hippopus procellanus* was added by Rosewater (1982). A workshop on giant clams was held in April 1988 at James Cook University, Townsville, Australia. The results, which include 54 separate contributions, contain the most current information on the biology and culture of giant clams (Copland and Lucas, 1988).

The currently described species are:

Tridacna gigas (Linnaeus, 1758)
Tridacna derasa (Roding, 1798)
Tridacna squamosa Lamarck, 1819
Tridacna maxima (Roding, 1798)
Tridacna crocea (Lamarck, 1819)
Tridacna tevoroa (Lucas, Ledua and Braley, 1990)
Tridacna rosewateri (Sirenko and Scarlato, 1990)
Hippopus hippopus (Linnaeus, 1758)
Hippopus porcellanus (Rosewater, 1982)

All living tridacnid clams live in the Indo-west Pacific; none in the Hawaiian Islands. The larger members of the family have been listed as threatened by IUCN (1983).

Local overharvesting has greatly reduced wild stocks. *Tridacna gigas* is extinct at Guam and the Mariana Islands, the Federated States of Micronesia (Yap, Chuuk, Pohnpei, and Kosrae) Fiji, New Caledonia, Taiwan, the Ryukyu Islands and Vanuatu; *T. derasa*, at Vanuatu; and *H. hippopus*, at Fiji, Tonga, Western and American Samoa, Guam and the Mariana Islands, and Taiwan (Munro, 1989). Munro (1989) reviews information on the status and utilization of seven species in 32 countries.

Several hatcheries have been established, the larger ones being at Palau [Micronesian Mariculture Demonstration Center (MMDC)], Solomon Islands [Coastal Aquaculture Centre of ICLARM (CAC)], and Australia (Orpheus Island Research Station of James Cook University, Townsville). All of the larger species have been successfully reared. Hatchery-reared individuals have been distributed throughout the Pacific to reseed and to establish population in lagoons and coastal areas (see list below).

In June 1992, ICLARM held a workshop on 'Genetic aspects of conservation and cultivation of giant clams' in Manila. This workshop was convened to 'to promote regional cooperation in breeding giant clams, and provide a forum for discussion of the re-establishment of stocks in a genetically sound way' (Munro, 1993, p. iv). Along with discussion papers, there were six country reports. Recent studies have shown that there is significant genetic structuring among the Pacific giant clam populations. Care must be taken that restocking does not eliminate local diversity; transfers should not be made, for example, between Australia or the Solomon Islands and Micronesia, since appropriate material already exists in the Marshall Islands (Benzie, 1993).

Transport of adults or juveniles also allows the transport of potential diseases, parasites, or predators. The diseases and parasites identified from giant clams include seven bacteria and bacterial diseases; a nematode, a trematode, and a turbellarian; Rickettsial infections, and three protozoans and protozoan diseases (Humphrey, 1988). No virus or viral diseases have yet been reported.

The snail predator *Cymatium muricinum* is most well known (Perron et al., 1985). This species is widely distributed and preys on a variety of bivalves. The larvae of *C. muricinum* settle from the plankton and although they are not known to occur in high densities, large numbers have been found feeding

on juvenile giant clams in land-based nurseries (Heslinga and Watson, 1985). Caution should be taken when transporting giant clams that *C. muricinum* not also be transported. Itano and Buckley (1988) reported that *C. muricinum* began appearing at the Alofau (American Samoa) nursery site about four months after the introduction of *T. derasa* from Palau. The snail *Chicoreus ramosus* is another giant clam predator (Heslinga et al., 1984).

The pyramidellid snail *Tathrella iredalei* is an ectoparasite on giant clams. At Palau (MMDC) infestations occur in land-based tanks which have been in culture for more than 3 months (Heslinga et al., 1990). Eggs or juveniles enter through the seawater system. AT MMDC, *T. iredalei* lay egg masses on the undersides of the clams. The nonplanktonic, nonfeeding larvae hatch as juveniles in about 15 days. Isolated infestations develop and spread throughout the tanks as more juveniles are produced (Heslinga et al., 1990). Smith (pers. comm.) reported that *T. derasa* received at Guam in 1989 probably carried egg masses with them, since *T. iredalei*, previously unknown at Guam, is now probably established. Further, (Govan, 1992) pointed out that undetermined species of pyramidellid snails have been reported on giant clams imported to Fiji, Guam, Hawaii, the Philippines (Negros), as well as to Florida and Bonaire. At Orpheus Island Research Station, a pyramidellid, *Turbonilla* sp. (identified as *Pyrgiscus*) (Cumming, 1988), is found in seawater tanks, is an ectoparasite of juvenile *T. gigas*, and appears to be the same one found in the Solomon Islands (Cumming, 1993). At Palau, *T. iredalei* is controlled by periodically emptying the tanks and changing the gravel (Heslinga et al., 1990). Information on numerous predators, primarily gastropods, has been compiled by Govan (1990).

Numerous transplantations of at least four species have taken place throughout the Pacific islands. In the Solomon Islands *T. gigas* broodstock has been transported to Guadalcanal and thousands of cultured juveniles from the CAC have been taken to other islands within the Solomons; however, such movements are all within the drifting range of a larval clam (Munro, pers. comm.).

Below, giant clam transfers are listed by species and island group. Additional transfers of species continue to take place in the aquarium trade. In 1984, test marketing of 100-120mm *T. derasa* was initiated at aquarium stores at Guam (Heslinga, 1989). Specimens from Palau (MMDC) for the aquarium trade began being sent to/through Hawaii in 1987. Between then and January 1991, approximately 13,000 clams of varying sizes were transshipped (Heslinga, pers. comm.).

Chronological list of giant clam transfers and introductions by species and country:

Tridacna derasa [Smooth Giant Clam]

American Samoa
- 1986: Palau (MMDC) to Tutuila
  - 1,000 16-month old specimens (71.69 mm average size) (transported through Honolulu, 894 survived); 671 to Alofau,201 to remain at Office of Marine and Wildlife Resources, predation by *Cymatium muricinum* (Anon., 1986; Itano and Buckley, 1988); of juveniles imported in 1986, now 450 mature broodstock (Anon., 1992)
- 1991: Palau (MMDC) to American Samoa
  - 18 clams (238.8 mm); 2,000 yearlings to workshop participants (MMDC, 1991)

Chuuk
- 1991: Palau (MMDC) to Chuuk
  - 2,000 yearlings to workshop participants (MMDC, 1991); 2,000 additional (Heslinga, n.d.)
- 1992: Kosrae to Chuuk
  - 3,000 1.4 year-old clams (Lindsay, 1993)

Cook Islands
1986: Palau (MMDC) to Aitutaki
1,000 juveniles; heavy predation by *Cymatium muricinum*; cyclones (January 1987) disturbed trays and scattered specimens; [Note: this is first introduction of *T. derasa* outside its native ranges in Polynesia] (Sims and Howard, 1988)

Federated States of Micronesia and Marshall Islands
1988: Palau (MMDC) to Kosrae, Yap, Pohnpei, Chuuk, and Majuro
1,000 juveniles to each FSM state marine resource divisions for culture; at Kosrae, 60% survival by June 1987, predation by *Cymatium muricinum* (Riley, 1992)

Fiji
1985: Palau (MMDC) to Fiji
500 juvenile clams, all died shortly after arrival (Adams, pers. comm.) [Note: this was MMDC's first shipment to the South Pacific]

Guam
1984: Palau (MMDC) to Guam
100 3-year old clams (3.75 pounds each) planted at Cocos Island (PFDF, 1985)
1989: Palau (MMDC) to Guam
test marketing (100-120 mm) specimens to aquarium stores (Heslinga, 1989)
1989: Palau (MMDC) to Guam
100 5-year olds to Guam, 87 transplanted to Apra Harbor during September 1989 and January 1990, survival not too successful; another ship of 6-month old and 2-year old clams held at GADTC, no releases (FitzGerald, pers. comm.)

Kosrae
1988/91: Palau (MMDC) to Kosrae
20,000 (3-5 mm) clams, cultured for 15 months, half distributed summer 1992 to Yap, Pohnpei, Chuuk; 50,000 (1-2 mm) maintained in pools; in 1991 2,000 (80 mm), in 1990 2,000 (52 mm), in 1989 2,000 (62 mm) and 1,000 (54 mm), 1988 1,000 (74 mm) (Riley, 1992)
1991: Palau (MMDC) to Kosrae
2,000 yearlings to workshop participants (MMDC, 1991)

Mariana Islands
1986/88: Palau (MMDC) to Saipan
in 1986: 500 (65.7); in 1987 100 (160 mm), 200 (161 mm);1988 200 (163 mm); another 2,000 (Heslinga, pers. comm.)
1991: Palau (MMDC) to Saipan
2,000 yearlings to workshop participants (MMDC, 1991); 2,000 additional (Heslinga, n.d.)

Marshall Islands
1985/90: Palau (MMDC) to Marshall Islands
in 1985 3,000 clams of various sizes to Majuro, ranging between 73.2 and 97.2 mm; in 1989 1,000 (64 mm) to Enewetak; in 1990 16,000 clams, various sizes, ranging between 31 and 65.7 mm (Heslinga, pers. comm.) (to lagoons at Mili, Likiep, and Majuro)

Pohnpei
1985/90: Palau (MMDC) to Pohnpei
in 1985 1,250 (23.6-93.2 mm); in 1989 1,000 (73.8 mm); in 1990 1,000 (10-20 mm) (Heslinga, pers. comm.) 1992 Kosrae to Pohnpei 3,000 1.4-year old clams (Lindsay, 1993)

Tuvalu
1989: Palau (MMDC) to Tuvalu
1,000 clams (145 mortalities); predation by *Cymatium muricinum* and *C. aquatile* (ACIAR, 1992)

Western Samoa
?: Palau (MMDC)to Western Samoa
specimens under cultivation by Samoa Marine (Anon. 1990)

Yap
1984: Palau (MMDC) to Yap
1,014 clams (84 mm) held 3 months, 18-month clams transported to four other sites at Yap; January 1986 distributed to 28 villages, three other sites added, totaling 31 plant sites; predation by *Cymatium muricinum* and *Chicoreus ramosus* (Heslinga and Watson, 1985; Price and Fagolimul, 1988)
1985: Palau (MMDC) to Yap
1,000 reared at Yap proper for 9-12 months, 658 clams transported to outer islands, each inhabited outer island received 30 clams for the lagoon (Price, 1988; Lindsay, 1991)
1986/87: Palau (MMDC) to Yap
6,000 clams to ocean nursery in Rumung; 6 months later 50 clams each distributed to 53 villages, remaining specimens transplanted to outer islands in 1988 (Price, 1988; Lindsay, 1991)
1991: Palau (MMDC) to Yap
2,000 yearlings to workshop participants (MMDC, 1991); 2000 additional (Heslinga, n.d.)
1992: Kosrae to Yap
100 clams (Riley, 1992); 3000 1.4-year old clams (Lindsay, 1993)
1993: Palau (MMDC) to Yap
10,000 seedlings to ocean nursery

Tridacna gigas [Giant Clam]

American Samoa
1991: Palau (MMDC) to American Samoa
2,000 yearlings to workshop participants (MMDC, 1991)

Chuuk
1991: Palau (MMDC) to Chuuk
2,000 yearlings to workshop participants (MMDC, 1991)

Cook Islands
1991: Australia (JCU) to Aitutaki
11,000 clams, quarantined at Aitutaki hatchery/nursery (ACIAR, 1992)

Fiji
1986: Australia (JCU) to Fiji
2,000 juveniles from Orpheus Island to quarantine tanks at Makogai Island for reintroduction (Ledua and Adams, 1988; ACIAR, 1992)
1987: Australia (JCU) to Fiji
475 juveniles, 419 survived quarantine (Ledua and Adams, 1988)
1990: Australia (JCU) to Fiji
7,000 clams (ACIAR, 1992) including 5,000 tested in shipping trials, to go to quarantine at Makogai Island (Braley, 1992)

Guam
1982: Palau (MMDC) to Guam
500 juveniles released, unprotected, heavy predation, unsuccessful (Munro and Heslinga, 1983; Heslinga, 1989) (Heslinga and Watson, 1985)

Kosrae
1991: Palau (MMDC) to Kosrae
8,000 1-2 year-old [4,000 (29 mm), 2,000 (unknown size), 2,000 (45 mm)] specimens (Riley, 1992)
1991: Marshall Islands (Reimers Enterprises) to Kosrae
56 3-4 year-old specimens (Riley, 1992)
1991: Palau (MMDC) to Kosrae
2,000 yearlings to workshop participants (MMDC, 1991)

Pohnpei
1990: Palau (MMDC) to Pohnpei
10,000 clams (10-20 mm) (Heslinga, pers. comm.)

Saipan
1991: Palau (MMDC) to Saipan
2,000 yearlings to workshop participants (MMDC, 1991)

Tonga
1991: Australia (JCU) to Tonga
11,000 11-month old, October 1991, 2,800 to Vava'u, 1,000 to Ha'apai, remaining 3,600 remained at Tongatapu (ACIAR, 1992; Fa'anunu, pers. comm.)

Western Samoa
1990: Australia ('Great Barrier Reef') to Western Samoa
1,300 juveniles by Samoa Marine after quarantine at Fisheries Division transferred to farm at Aleipata (Anon., 1990)
1991: Australia (JCU) to Western Samoa
11,000 clams in May; 6,000 in July (ACIAR, 1992)

Yap
1991: Palau (MMDC) to Yap
2,000 yearlings to workshop participants (MMDC, 1991)

Tridacna squamosa [Fluted Clam]

Guam
1982: Palau (MMDC) to Guam
500 juveniles released, unprotected, heavy predation, unsuccessful (Heslinga, 1985, 1989)

Western Samoa
1990: ? to Western Samoa
under cultivation by Samoa Marine (Anon., 1990)

Tridacna tevoroa

Fiji
?: Tonga to Fiji
500 juveniles to Makogai Island, 2% mortality (Ledua, 1993)

Hippopus hippopus [Horse's Hoof, Bear Paw, or Strawberry Clam]

Chuuk
1991: Palau (MMDC) to Chuuk
2,000 yearlings to collaborators (Heslinga, n.d.)

Cook Islands
1991: Australia (JCU) to Aitutaki
20,000 clams quarantined at Aitutaki hatchery/nursery (ACIAR, 1992)

Fiji
1991: Australia (JCU) to Fiji
20,000 clams quarantined at Makogai Island (ACIAR, 1992)

Kosrae
1990/91: Palau (MMDC) to Kosrae
in 1990 3,000 (53 mm), 1,000 (62 mm) in 1991, 1-2 year old clams (Riley, 1992)
1991: Pohnpei to Kosrae
50 specimens, approximately 5 years old; spawned in September 1991, all veligers died (Riley, 1992)
1991: Palau (MMDC) to Kosrae
2,000 yearlings to collaborators (Heslinga, n.d.)
1992: Marshall Islands (Reimers Enterprises) to Kosrae
40 individuals (Riley, 1992)

Saipan
1991: Palau (MMDC) to Saipan
2,000 yearlings to collaborators (Heslinga, n.d.)

Tonga
1991: Australia (JCU) to Tonga
20,000 11-month old specimens, transferred to ocean nursery at Tongatapu (February 1992) (Fa'anunu, pers. comm.)

Western Samoa
1991: Australia (JCU) to Western Samoa
20,000 specimens (ACIAR, 1992)
1990 and 1992: Solomon Islands (ICLARM/CAC) to Western Samoa
216,000 larvae (18-day) and 43,000 larvae (25-day), all died (Bell and Munro, pers. comm.)

Yap
1991: Palau (MMDC) to Yap
2,000 yearlings to collaborators (Heslinga, n.d.)

The first giant clam introduction to Hawaii was in March 1951 when 60 individuals of *T. crocea* from Rose Island were placed in holding ponds at Coconut Island, Kaneohe Bay, Oahu (Brock, 1952). A few were still alive in 1959 but there was no evidence of reproduction (Brock, 1960). At some time later, the remaining specimens were collected and sent to the Steinhart Aquarium in San Francisco (Jokiel, pers. comm.). *Tridacna gigas* and *T. squamosa* were shipped to Hawaii from Palau (MMDC) beginning in 1985 (Heslinga, 1989, pers. comm.; Heslinga et al., 1984).

Giant clams have also been shipped to the Caribbean where an estimated 600 clams from Palau were reportedly being cultured in Bonaire, Guadeloupe, and south Florida (Williams and Bunkley-Williams, 1990; Williams and Sindermann, 1992). The Fundashon Marcultura at Bonaire (Netherland Antilles) is presently (mid-1993) growing *T. derasa* (originally from MMDC, Palau, in 1988) and *T. maxima* and *T. crocea* (from wholesalers in Miami, Florida). Spawning has been observed in home aquariums with lowered salinity but not at the major facility (Berkers, pers. comm.)

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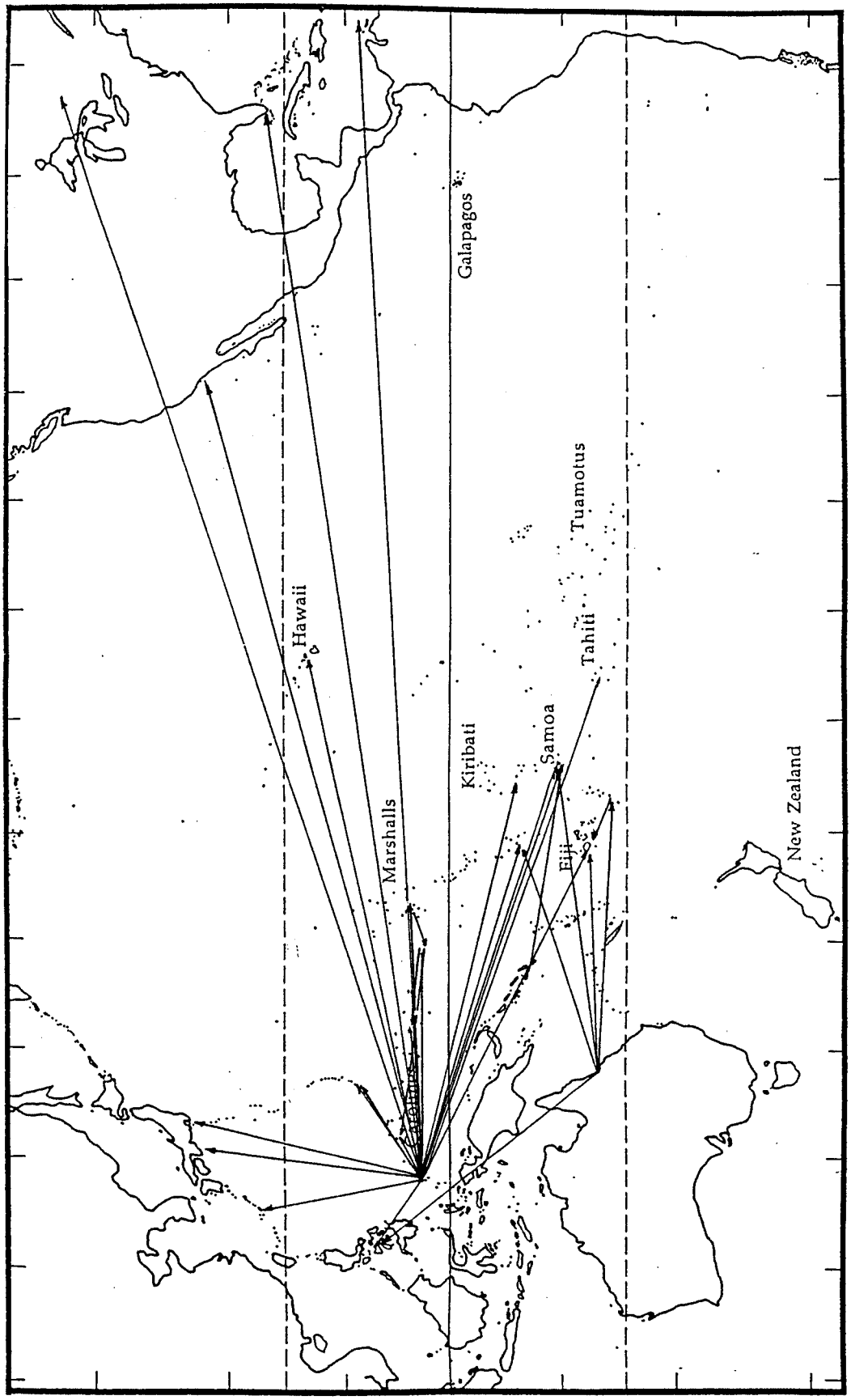
Tridacna **grow-out tanks at Micronesian Mariculture Demonstration Center, Koror, Palau**

Tridacna derasa **on reef flat [Photos: R. H. Richmond]**



Tridacnid clams – generalized map of tridacnid clam transfers among the Pacific islands, all species included; each direction of transfer is indicated only once, although numerous transfers may have occurred in that direction.

OYSTERS (Family Ostreidae)

Oysters are found worldwide throughout temperate, subtropical, and tropical waters. Many are harvested from local stock for local consumption. Numerous species have been transported throughout the tropics—most such introductions have not been successful. The biology and culture of tropical oysters have been reviewed (Angell, 1986).

Species belonging to the genera *Crassostrea*, *Ostrea*, and *Saccostrea* are the most widely utilized. Historically, the taxonomy of these has been confused (Torigoe, 1981; Arakawa, 1990a). Features of the shell are used to differentiate the genera. Individuals of *Saccostrea* have denticles (chomata) at the hinge, a deep umbonal cavity, and a tendency to grow in a cornucopia (rudistiform) shape; those of *Ostrea* have denticles but no umbonal cavity, and grow in a subcircular, flat shape; and those of *Crassostrea* have no denticles, a moderate umbonal cavity, and grow in a somewhat elongated and cupped shape (Angell, 1986).

Below is a chronological summary of oyster introductions to south Pacific islands [it should be noted that information from different sources vary slightly as to number of individuals introduced and date of introduction] (modified from Uwate et al., 1984, with additions and modifications):

Crassostrea belcheri

Tonga
- 1977: specimens from Sabah evaluated in intertidal racks in the Nukunukumotu Channel, some sent to Vava'u
- 1978: 100,000 individuals (mixed with *Perna viridis*) from Sabah attached to strips in intertidal racks between Nukunukumotu Island and Tongatapu
- 1981: culture trials terminated, since being poorly monitored

Crassostrea echinata [Australian oyster]

Fiji
- 1910: individuals from Australia [by the grandfather of a Mr. Borron, owner of Mago Island in the Lau Group (Glude, 1972)] planted in Mago Island lagoon. 1971: one shell found in the Namuka area, west of Suva
- 1981: 2,280 seeds from CNEXO (Tahiti) planted at Laucala and Namarai Bays; high mortality because of siltation and abundant brown algae, project suspended at end of 1981 (Vereivalu, 1990)

French Polynesia [see also Coeroli et al., 1984]
- 1972: SPIFDA-supplied individuals from New Caledonia
- 1978: additional specimens from New Caledonia; 2 million spat produced at COP (CNEXO), thought to be less sensitive to *Polydora*
- 1983: additional specimens from New Caledonia

Guam [see also Braley, 1984]
- 1979: approximately 700 specimens from Koror, Palau, planted at 4 sites in Sasa Bay, Apra Harbor (Braley, pers. comm.)

New Caledonia
- 1979-1980: 1,650,000 eggs imported from Tahiti, survival good, 20,000 still cultivated in 1983

Crassostrea gigas [Pacific oyster, Japanese oyster] [see also Glude, 1984]

Fiji

1968: individuals from Japan in raft culture, theft in 1969 terminated experiments
1969: seed oysters from Japan planted at Bay of Islands near Lami, good growth and survival; second introduction from Japan planted at Namarai Bay, harvested
1970: shipment from Japan planted in Namarai Bay again, most died
1971: 5,000 seed from California cultured at Cave Island in Bay of Islands (hurricane damage in 1973)
1972: 200,000 cultchless seed from California, erratic growth, some survival; receipt of a shipment of 45 kg of cultched spat, 25% survival reported
1973: 2 mt cultched spat from Japan, considerable mortality because of Nadi Airport strike; 20,000 spat from Australia, high mortality at Bay of Islands; one million cultchless spat from California
1974: 2 mt (900,000) spat from Japan put in raft culture; one million spat from U.S., cultured at Rewa Delta, heavy predation by *Scylla serrata*
1975: unidentified introductions
1976: specimens imported from Philippines, cultured but no growth in 14 months
1977: additional introductions; 100,000 from an American supplier, 100% mortality (Bourne, 1979)

French Polynesia

1972: unspecified introductions received from a Mr. T. Lenai; in August seed introduced from California, individuals (to Tahiti, Raiatea, Tahaa) had little growth because of heavy *Polydora* infestation
1976: seed stock from California, 90% mortality, *Polydora* infestation and *Scylla serrata* predation

Guam

1975: 11,550 spat (431 collector shells) from Taiwan (photo of raft culture at mouth of Talofofo River) (FitzGerald, 1982), considered unsuccessful

New Caledonia

1967: few specimens from Japan
1971: spat to Noumea (from Australia?)
1970-1977: numerous unspecified introductions from Japan and California
1976-1977: about 40,000 eggs (probably *C. gigas*) imported from COP hatchery in Tahiti

Palau

1972: approximately 100,000 spat from California, initial mortality 27% (Pflum, 1972), 40% dead by January 1973
1973: additional 100,000 cultchless spat from California, 40% mortality within 6 weeks (Tufts, 1973); 6,500 cultched from Washington State (September 1973)
1975: 25,000 imported (unspecified locality) planted at Ngetpang Bay

Tonga

1974: unspecified introduction, poor growth rate in 1975
1975: cultched spat imported from Tasmania and Japan, heavy mortality, predation by drill (*Cymatium*)

Vanuatu

1972: 20,000 unattached spat from California to Espiritu Santo (following recovery in New Caledonia)
1973: approximately 600,000 spat imported from California to Mounparap Bay; additional 100,000 from California to Port Sandwich, Malekula; some additional trials at Efate near Pt. Vila

Western Samoa
?: no information other than arrow on map showing recent transfer from U.S. northwest (Chew, 1990)

Crassostrea iredalei [Philippine oyster]

Fiji
1975: about 300 specimens from Cavite, Philippines, transported, all killed in flood six months later
1976: additional specimens from Philippines, quarantined in New Caledonia, 22% mortality

Tonga
1976: under cultivation, source unknown

Crassostrea virginica [American oyster]

Fiji
1970: specimens from Hawaii planted at Bilo Bay

Tonga
1973: 10,000 spat mixed with *C. commercialis* from California through Fiji

Ostrea edulis [Flat oyster, European native oyster]

Fiji
1977: spat introduced [from undisclosed locality; from Japan (Andrews, 1985)] by private farm which closed after growth to marketable size

Tonga
1975: several shipments from Japan and California, high mortality

Saccostrea commercialis [=***Crassostrea commercialis***, includes *S. glomerata*] [Sydney rock oyster, Australian rock oyster]

Fiji
1880s: specimens thought to have been introduced from Australia, planted near Savusavu, Vanua Levu (Glude, 1972)
1968: introduction from Australia, spatfall in 1969
1970: from Australia, planted at Bilo Bay
1973: introductions from California, cultured at Taveuni, Savusavu, and Labasa; growth stopped January 1974 (Ritchie, 1974)

New Caledonia
around 1971: adult specimens from Australia to Ouenghi area of Baie St. Vincent, kept in trays, sold locally

Tonga
1973: 10,000 (?*C. glomerata*) from New Zealand to Fanga'uta Lagoon, Tongatapu; 10,000 spat (mixed with *C. virginica*) from California

Saccostrea cucullata tuberculata [Solomon Island mangrove oyster]

Guam [see also Braley, 1984]
1978: 45 specimens form Solomon Islands arrived (4/12/78), held, and planted (4/11/79) in Sasa Bay, Apra Harbor (Braley, pers. comm.)

Unidentified Oysters

Fiji

1973: 200,000 cultchless spat imported from California

Hawaii has had a long history of oyster introductions. *Crassostrea virginica* seed was first planted in Pearl Harbor in 1866. Additional introductions to Oahu were in 1877 to Honolulu, 1883 to Kaneohe Bay, 1890 to Moanalua, and 1893 and 1895 to Pearl Harbor. Systematic introductions were begun in the 1920s to Kaneohe Bay and Pearl Harbor (Kay, 1979). *Crassostrea gigas* was brought from Japan and planted at Kalihi, Oahu, in 1926, and in 1938 and 1939 shipments were set out at Pearl Harbor and Kaneohe Bay, Oahu (Brock, 1960). Individuals have also been received from the northwest U.S. (Chew, 1990). Kay (1979) indicated that both species on Oahu as well as in fishponds on Molokai, have commercially valuable populations. In addition, *C. amasa*, *C. commercialis*, *C. virginica*, and *Ostrea lurida* have been introduced but not successfully established (Brock, 1960; Kay, 1979). Hawaii was the source of specimens of *C. virginica* introduced to Fiji in 1970 (Andrews, 1985).

Oyster introductions into the south Pacific have, for the most part, not been successful. The Pacific oyster (*C. gigas*), originally from Japan and introduced in the early 1900s to north America, is the most often transported species. No commercial production has resulted (Angell, 1986). Bourne (1979, p. 45) noted, 'one can only conclude that *C. gigas* does not appear to be a suitable oyster for culture in the tropical islands of the South Pacific.' Glude (1984) noted that *C. gigas* introductions 'failed because of high mortalities during the second year' (p. 37). He added that there was little interest in continuing to culture it. High temperatures and predation may account, in part, for the lack of success.

Oyster shells provide an ideal substrate for a variety of attached (sessile) and sedentary plants and animals. Most often these are just nuisance organisms which cause no problems but may cause mortality by growing over the animals themselves. However, disease-producing organisms, predators, parasites, and other obnoxious organisms might be associated. This may be referred to as fouling or biofouling. Some examples of these are: sponges, especially *Cliona* which can bore into shells, forming a series of tunnels; sea anemones and corals; erect or encrusting bryozoans; tube worms, especially *Polydora* (mud blister worms) whose burrows fill with mud and occasionally break through, causing the oyster to secrete a new layer of shell; and barnacles and tunicates. Algae and bacteria can also be found on oyster shells. Fouling may be controlled by the following methods: physical (air drying in sun), chemical (placing in freshwater, applying chemicals such as copper sulfate or brine), and biological (becoming familiar with the life history and ecology of fouling organisms to take advantage of natural systems) (Quayle and Newkirk, 1989).

In the Pacific area at Palau, observations at the Micronesian Mariculture Demonstration Center showed that in oyster pens which also contained the siganid fish *Siganus canaliculatus*, another maricultured animal, fouling organisms were not found. In empty pens without the fish, there was extensive growth of algae and other animals (Hasse, 1974).

In his review of *C. gigas* in the Pacific islands, Bourne (1979) specifically noted that with best information available no other exotic species were introduced with *C. gigas* seed to Palau, Vanuatu, New Caledonia, Fiji, Tonga, and Tahiti. He further added that this may have resulted because the seed originated at hatcheries and relatively small numbers of seed were introduced for only short periods of time.

Information concerning parasites and diseases among the islands is virtually nonexistent. No viral or bacterial diseases have been reported (Angell, 1986). A list of known parasites of *C. gigas* and *C. virginica* has been prepared (Cheng, 1967). A thorough review of competitors and fouling organisms associated with *C. gigas* details species which grow on the shells and some prevention and eradication measures (Arakawa, 1990b).

Hartmannella tahitiensis is an amoeba associated with a mass mortality of *C. commercialis* at Vahi tarua, Port Phaeton, Tahiti, in 1968 (Cheng, 1970). Specimens were alive but moribund when examined. Since *H. tahitiensis* is a soil animal, Cheng hypothesized that with the freshwater runoff and erosion individuals were washed into the estuary where they entered the oysters. He further added that the

amoeba 'should be considered as a facultative parasite of moribund oysters or, more appropriately, as a secondary invader of necrotic tissues rather than as a true parasite' (Cheng, 1970, p. 418). The species may not cause a problem if transported, since it does not attack healthy oysters.

Information on marine fungi is scarce; however, Lee et al. (1982) reported a mass mortality in Pearl Harbor, Oahu, in 1972 in which 99% was thought to be caused by fungal infection. Pearl Harbor might otherwise be considered a source of seed oyster. A mycelial disease (*Perkinsus*) is known from *C. gigas* and *C. virginica* in the U.S. (Quayle and Newkirk, 1989).

Flatworms of the genera *Stylochus* and *Pseudostylochus* are known to feed on oysters. In Hawaii, Brick (1970) reported heavy predation by an undescribed species of *Stylochus* on *C. gigas* and *C. virginica*. He reported 100% mortality after suspending two oyster racks in Kaneohe Bay, Oahu. Dead oyster shells contained one to five flatworms. In a second trial two week later, 40% mortality occurred within ten days. Hallier (1977) reported high mortality in *C. gigas* caused by a *Pseudostylochus* in 1975 and early 1976 at Lamap, Port Sandwich Bay, Malekula Island, Vanuatu.

Mud blister worms, *Polydora* spp., are closely associated with oysters. Individual worms bore into mollusk shells, forming a small mud-filled cavity. The blisters which form on the inner surface of the shell lower the marketability of the oyster and can cause public health problems. The best documented cases of *Polydora* infestation are in Hawaii. *Polydora websteri* was introduced into land-locked oyster runways either from individuals transferred from Kaneohe Bay or from oyster spat imported from the U.S. mainland. The infestation was so extreme that the oyster culture operation was eventually abandoned (Bailey-Brock and Ringwood, 1982).

Polydora nuchalis was introduced to Oahu (possibly with penaeid shrimp from western Mexico). This species of worm forms masses of mud tubes, accumulating large amounts of sediment, and may completely block drains and pipes. Transfer from one site to another is carried out easily when oysters are transported (Bailey-Brock, 1990)

Polydora infestations have been reported from French Polynesia in *C. gigas* which appeared not to be very resistant. An experimental hatchery for *C. gigas* closed after three years because *C. gigas* did not appear to be commercially culturable (Uwate et al., 1984). *Crassostrea echinata* appears to be less sensitive to *Polydora* (Uwate et al., 1984).

Several different snail species are predators on oysters. Among the more important are the oyster drills (family Cymatidae) but little is known about them among the Pacific islands. In Tonga, unexplained mortality reduced stocks of *C. gigas*, and the remaining individuals were killed by the drill, *Cymatium* (Uwate et al., 1984). The mud crab *Scylla serrata* also preys on oysters.

Any or all of the above organisms can be transported either as juveniles or adults on oyster shells or in contained water when they are transferred from culture area to culture area or from island to island. Caution is of utmost importance in order to avoid disaster.

Some public health problems can arise from transporting oysters. Red tides caused by the dinoflagellate *Pyrodinium bahamense* are known to produce paralytic shellfish poisoning or PSP. This is the result of eating bivalves (oysters, mussels, etc.) which have been harvested during red tides. Deaths may occur as a result of respiratory failure within 12 hours. PSP has been around Papua New Guinea for many years and has been spreading rapidly to Palau, Guam, Tuvalu, Fiji, and the Solomon Islands (Maclean, 1984).

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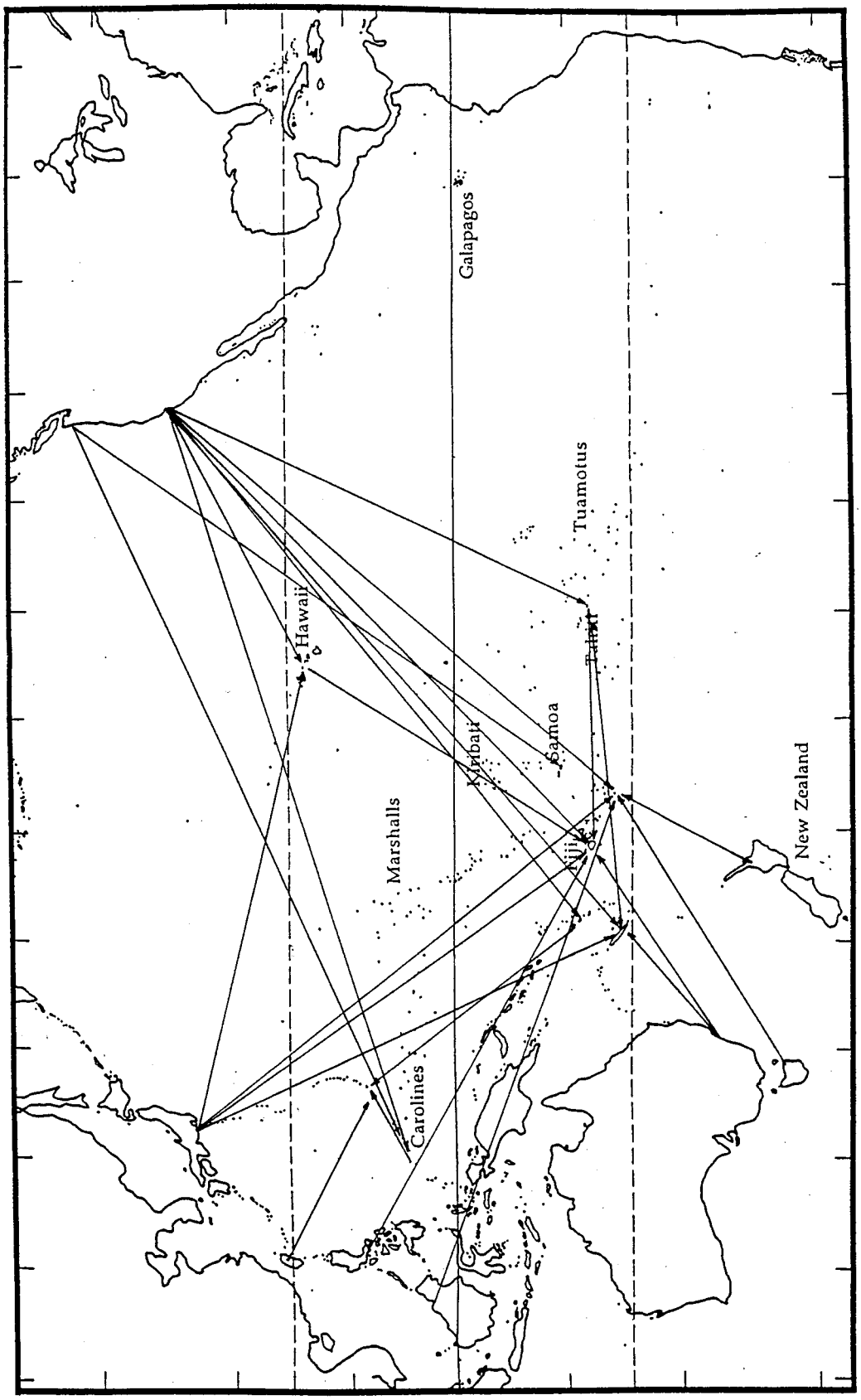

Oysters – generalized map of oysters transfers among the Pacific islands, all species included; each direction of transfer is indicated only once, although numerous transfers may have occurred in that direction.

GREEN MUSSEL [*Perna viridis*]

Green mussels, *Perna viridis* (formerly known as *Mytilus viridis* and *Mytilus smaragdinus*), are marine bivalves with thin green shells which live attached to rocks and hard substrate in shallow waters. The biology and culture of three species of *Perna* have been reviewed by Vakily (1989). The taxonomy of the genus and the three species has been discussed by Siddal (1980).

Below is a chronological summary of green mussel introductions to south Pacific islands (modified from Uwate et al., 1984, with additions).

Cook Islands

1984: small collections from Tahiti informally introduced; unsuccessful (Sims, pers. comm.)

Fiji

1975: (April) 800 specimens brought from the Philippines, initial mortality high; individuals surviving showed excellent growth; spawning twice a year
1976: (January) additional specimens from the Philippines; 99% survival during first two months
1976: (October) additional imports
1981: grow-out trials at Namarai Bay, Laucala Bay, and Rewa delta at Suva; predation heavy; no evidence of natural spatfall; commercial production potential (Navakalomona, 1982), no projects implemented; trials terminated
1987: 1,500 surviving individuals cleaned, quarantined, and moved to Naqara for observation (Anon., 1987) [Fiji mussel project closed in 1989 (Adams, pers. comm.)

French Polynesia

1978: green mussel introduced from New Caledonia to Tatutu Bay and Uturoto Bay; spat production found viable (AQUACOP, 1979; AQUACOP, 1982)
1979: culture studies initiated; successful larval development and settlement (AQUACOP and de Gaillande, 1979); culture area caged to exclude principal predator (*Scylla serrata*)
1990: spat production continues, estimated 3 million annual production (Preston, 1990)

New Caledonia

1972: green mussels introduced from Manila Bay, Philippines, to Baie de Saint-Vincent (SPIFDA, 1972)
1976: second introduction from the Philippines; initially grown at private farm until 1978
1978: eggs to St. Vincent Station and 3 private farms
1979-1980: more than 3 million eggs successfully fertilized at one farm, others less successful
1983: mussel farming program initiated, mangroves and stream bed appeared adequate

Tonga

1975: transport from the Philippines attempted, no survival
1976: specimens imported from Singapore, survival rates encouraging; seeded in lagoons at Tongatapu, Pangaimotu, and Vava'u
1976: specimens from the Philippines, 40-50% mortality; also some raft culture, most died
1977: green mussels from Sabah cultured in Umisi area of Fanga'uta Lagoon, growth rates encouraging
1978: two shipments (100,000 individuals, including *Crassostrea belcheri*) from Sabah, good growth but trial culture did not provide meaningful results
1983: no further studies planned

Western Samoa
1981: study initiated
1982: (June) importation from Tahiti (40,000 81-day old spat), planted close to Apia
1983: (February) 70,000 spat, to remote areas of Savai'i and Upolu islands (Bell and Albert, 1983); 10% mortality

Western Samoa status reports are the most thorough (Bell and Albert, 1983; Bell, et al., 1983; Bell and Albert, 1984). In June 1982, 40,000 spat were received. Of these 3,000 were planted at Fisheries Harbour and 10,000 at Mulinu'u which had high mortality during the first month. Of those planted at Fisheries Harbour, only 220 remained in June 1983 when the rafts where dismantled. In the second phase of the culture, 40,000 spat were planted in Safata Bay (30,000 attached to rafts and 10,000 placed in trays) in February 1983. Of these, 3,500 remained in June 1983. Siltation and predation by crabs appeared to be a problem. At Asau on Savai'i, 30,000 spat were attached to two rafts in February 1983. In June of that year between 20,000 and 25,000 mussels remained, and in September 1983 the rafts were densely populated but no spatfall had been observed. One raft was completely harvested.

As with other mollusks, little is know about diseases, parasites, or predators of mussels. Vakily (1989) reported on earlier investigations and noted that in India potentially pathogenic bacteria were part of the normal flora of both the mussel and the surrounding seawater. Further, Vakily (1989) added that the crab *Scylla serrata* was also a predator in Brunei, Malaysia, and the Philippines. He also noted that in India and off the South African coast fish (Family Sparidae) prey on raft-cultured mussels.

Perna canaliculus, the New Zealand mussel, has been reported from Australia. Specimens from Tasmania are held in the Australian Museum. Individuals may have arrived through ship fouling but have apparently not become well established (Pollard and Hutchings, 1990).

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PEARL OYSTERS [*Pinctada* and *Pteria* species]

Marine species of pearl oysters (family Pteriidae) belong to two genera – *Pinctada* and *Pteria*. Specimens of *Pinctada* have subquadrate shells and a short hinge line; those of *Pteria* have extended hinge lines which form wing-like shells (Kay, 1979). The biology and culture of pearl oysters have recently been reviewed (Gervis and Sims, 1992).

Three species of *Pinctada* have been transported and cultivated among the Pacific islands. *Pinctada fucata martensi* (Japanese pearl oyster) occurs naturally in Japanese waters and was taken to Palau in the mid 1930s. The other two species – *P. margaritifera* (black-lip pearl oyster) and *P. maxima* (gold-lip pearl oyster) – occur more widely throughout the Indo-west Pacific region. *P. margaritifera* is found from the Red Sea and Persian Gulf to Hawaii and southeastern Polynesia, as well as in the Gulf of California and the Pacific coast of central America. *P. maxima* is restricted to the Indo-Malayan region from Burma eastward to the Solomon Islands and northward to south of Japan, including all of Malaysia, Indonesia, and the Philippines (Doumenge et al., 1991; Gervis and Sims, 1992).

The taxonomy of pearl oysters has a confusing history. More than 100 names have been proposed for what are now thought to be about a dozen species (Ranson, 1961; Doumenge et al., 1991). *Pinctada fucata martensi* has teeth on the hinge; the other two species do not. The shell of *P. margaritifera* is dark and slightly more convex than that of *P. maxima*. Adults of the latter species remain unattached; those of the former are attached by a byssus to solid substrate.

Pearl oysters have been transplanted since the beginning of the century (Saville-Kent, 1905). In the 1930s, Japanese interests introduced *P. maxima* to Micronesia, and in the 1970s there were several additional transfers. Since the species are widely spread, note is made here only of known introductions of individuals transported from one island to another (modified from Uwate et al., 1984, with additions).

Pinctada fucata martensi [Japanese pearl oyster or akoya]

Marshall Islands

1935-1936: specimens to Ebon from Japan for Mikimoto pearl farm(s); planting and operations abandoned in 1942

Palau

1935-1936: specimens from Japan for Mikimoto pearl farm(s); before World War II, eight separate farms were known in Palau; plantings and operations were abandoned in 1942 (Smith, 1947)

Tonga

1975-1977: 1,979 specimens to Vava'u from Tasaki Pearl Co., Amani, Japan along with *P. margaritifera*, *P. maxima*, and *Pteria penguin* (Tanaka, 1990)

Pinctada maxima [gold-lip pearl oyster]

Cook Islands

1904: Lever Brothers transplanted 1,500 specimens to Suwarrow Island from Cape York Peninsula in the Torres Straits (Saville-Kent, 1905)

Kiribati

1904: Lever's Pacific Plantation Ltd., transported pearl oyster to Christmas Island lagoon from the Torres Strait; unsuccessful

Palau

1935-1942: 77,460 shells transported from northwestern Australia and Indonesia (by the Arafura pearling fleet); 43,185 implanted, yielding 11,460 pearls 1942 pearl operations terminated

Tonga

197: 7 introductions from Tasaki Pearl Co., Amani, Japan

Pinctada margaritifera [black-lip pearl oyster]

Cook Islands

1955: individual shells from Manihiki to Rakahanga; later to Pukapuka (1956) and Palmerston (1957); successful (Noakes, 1959)
1980s: Department of Fisheries working with commercial company on spat collection to be distributed to grow-out facilities
1980s: several transfers to Rakahanga from Manihiki (4520 in 1982); two shipments in 1985

French Polynesia

ongoing: spat collection at Hikueru, Takapoto, and Takaroa seeded in lagoons of various islands
1979: spat from Okinawa to Takapoto (Millous, 1980)

Kiribati

1977: natural stocks transferred to Christmas Island, planted at sites east of Cook Island and northeast of Wood Island; specifics unknown [possibly remnants of the original native stock (Sims, pers. comm.)]

Tonga

mid-1970s: introductions from Tasaki Pearl Co., Amani, Japan

Unidentified pearl shell introductions, probably ***P. maxima***

Papua New Guinea

1977: 7,000 live 'mother-of-pearl' shells collected at Kuri Bay, Western Australia, to be planted in Fairfax Harbor, Port Moresby; promising, but polychaete infestation caused high mortality; farm closed because of economic considerations

Although native (but rare) throughout the Hawaiian Islands, 300 *Pinctada margaritifera* (formerly known as *P. galtsoffi*) from Pearl and Hermes Reef were taken to Coconut Island in Kaneohe Bay in September 1930, and in August 1950, 6 were added (Brock, 1952). Individuals of *Pinctada fucata martensi* were brought to Hawaii in 1956 (Kanayama, 1967).

Braley (1991) investigated the introduction of *P. margaritifera* to Tokelau and suggested that broodstock be obtained from the northern Cook Islands, since there would be probably less chance of transporting new parasites and diseases from a neighboring lagoon.

In 1975, individuals of the mabe shell or blister pearl (winged pearl shell) *Pteria penguin* were imported to Tonga from Japan. Growth was excellent. Additional specimens were received from the Tasaki Pearl Co., but prior to Hurricane Issac (March 1982) all mabe pearls were harvested; however, in 1983 some pearl shells were still being cultivated at other sites. In 1990, several specimens of *Pteria* were reported on FAD lines at Vava'u; there was no way of determining whether or not they originated from this earlier introduction (Tanaka, 1990).

Inter-island transfer of shells provides an opportunity for diseases and parasites to be further transmitted. Gervis and Sims (1992) reviewed fouling and boring organisms and parasites and pathogens. An additional associate is a mud-blister worm *Polydora pacifica* which forms bore-holes and produces tumor-like growths on the inner surfaces of the shells at Palau (Takahashi, 1937).

A virus, which first appeared at atolls in the Gambiers, is suspected to have caused the deaths of as many as one million shells at Takapoto in the Tuamoto Archipelago, and a ban on transfers was initiated (Anon., 1985). Additional mortalities have occurred. In 1985, 50% to 80 % of the stock died, in 1988 mortalities were still high (Cabral, 1989). These deaths apparently resulted from a variety of factors, including transfer of shells from one lagoon to another. The French Polynesian Ministry of the Sea authorizes transfers in an attempt to control the spread of diseases (Cabral, 1992). Diseases of cultured *P. margaritifera* in French Polynesia have appeared in wild stocks and other bivalves (Gervis and Sims, 1992).

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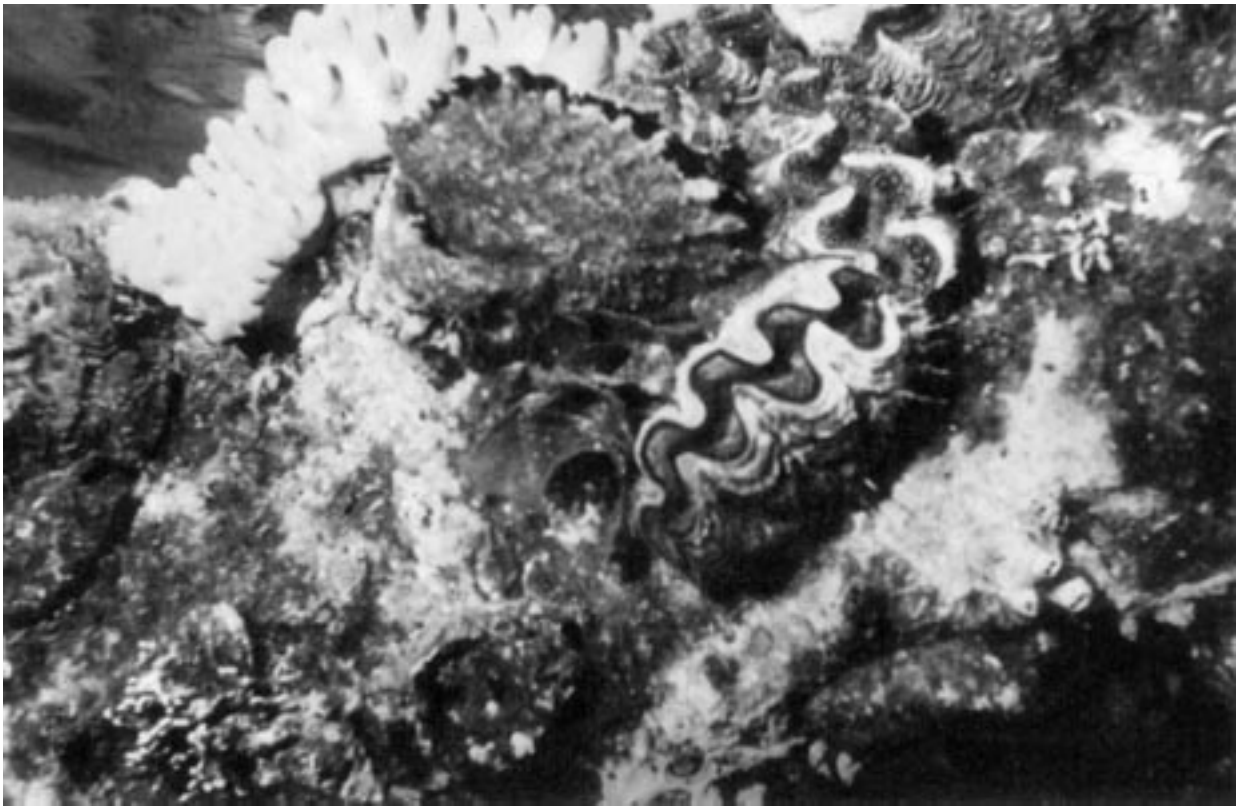
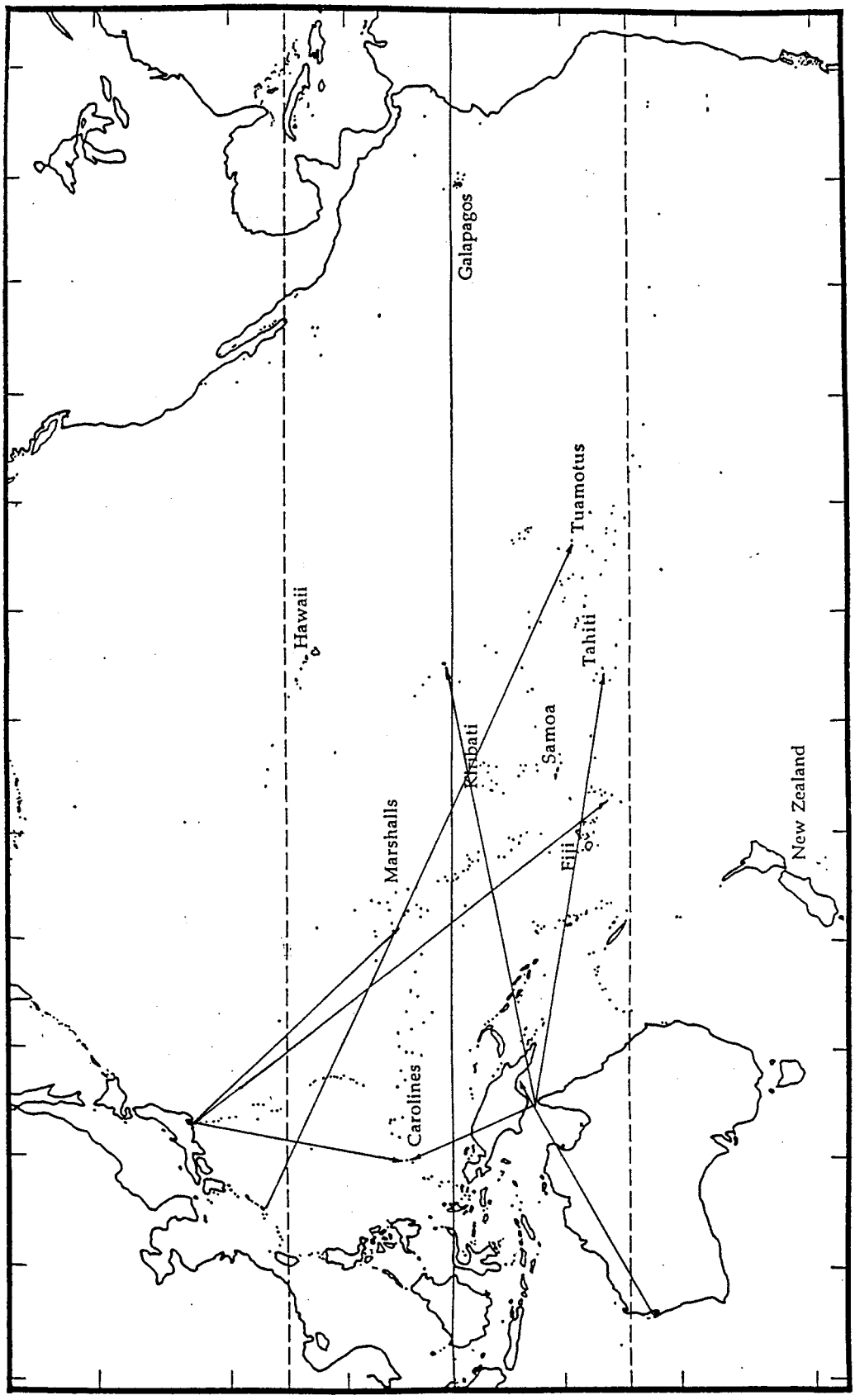


***Pinctada margaritifera* (upper middle) on reef flat with *Tridacna* [Photo: N. Sims]**



***Pinctada* species – generalized map of pearl oysters transfers among the Pacific islands, all species included; each direction of transfer is indicated only once, although numerous transfers may have occurred in that direction.**

FRESHWATER CLAMS [*Corbicula fluminea*]

The Asiatic clam *Corbicula fluminea* was widely introduced into North America in the early 1900s from south-east Asia. The species presently occurs from the U.S. west coast and southern states, throughout drainage east of the Mississippi River and into northern Mexico (McMahon, 1991).

In Hawaii, living Asiatic clams were first observed at an 'open market' in Kailua (Oahu) in August 1977, having been illegally imported through a Los Angeles exporter (Burch, 1978). Additionally, it was noted that previously confiscated *C. fluminea* had arrived from the Orient.

In 1982, *C. fluminea* was first discovered on Kauai (Devick, 1991a) where it had spread to at least 14 reservoirs and irrigation ditches and to five rivers and streams in eight watersheds (Heacock, 1991). In March 1988 the Asiatic clam was also found in a major irrigation system in central Maui but none had been found in streams (Hau, 1991). These clams have also been seen at local "swap meet" markets on the Big Island of Hawaii. Specimens were found on Oahu in 1988, in Manoa Stream (Oahu) in 1990 (Devick, 1991a), and at Kaneohe in 1992 (Burch, pers. comm.).

Asiatic clams were probably introduced by Asian immigrants for food, even though the first seen in Hawaii were from California. These clams grow rapidly and can completely block irrigation pipes and create large amounts of sediment in ditches. In California reservoir fishes are known to have declined because of competition for bottom-living food (Devick, 1991a). For the Pacific islands, all possible means to avoid introduction should be pursued.

In addition, individuals of a species of the clam *Musculium* had become established in reservoirs on Oahu and Maui by 1990 (Devick, 1991b).

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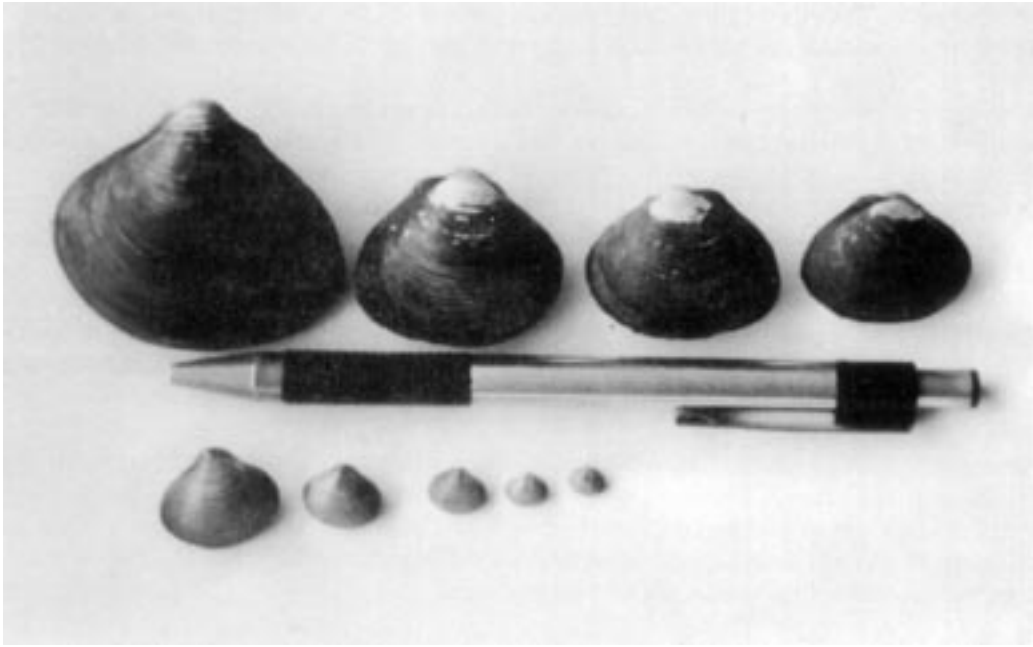
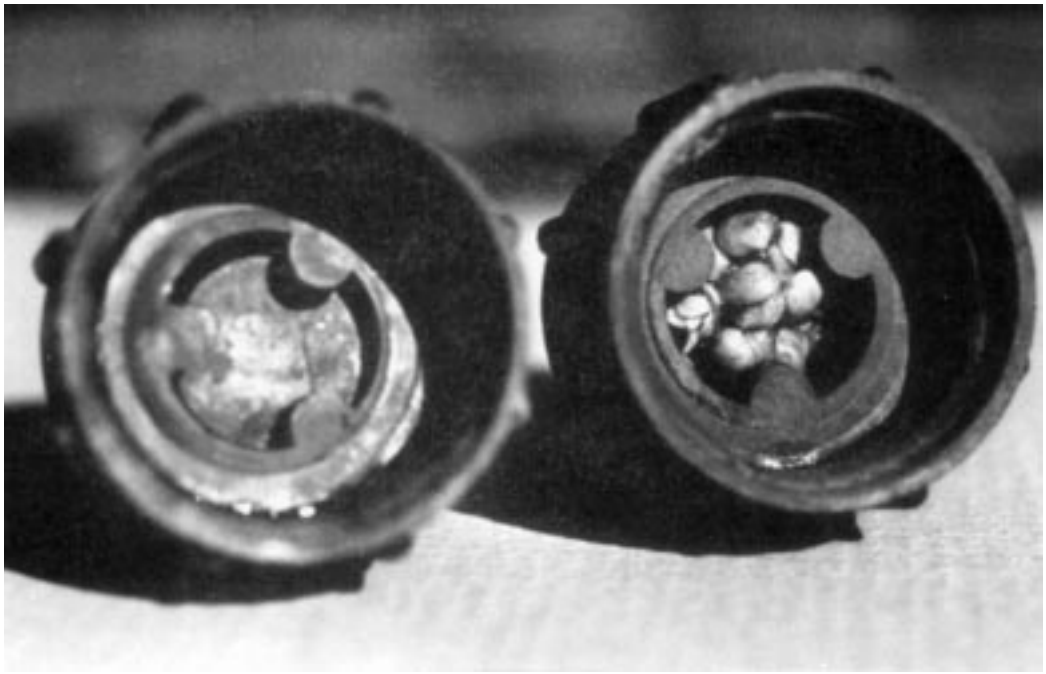


***Corbicula fluminea*, size series, Maui (Hawaii) [Photo: S. Hau]**



***Corbicula fluminea* blocking irrigation pipes, Maui (Hawaii) [Photo: S. Hau]**

OTHER BIVALVES

The first introduction of *Tapes japonica* [=*Venerupsis semidecussatus, V. philippinarum*] [Japanese clam, Manila clam] occurred at the turn of the century (Kay, 1979). In 1920, 10 barrels of clams were brought from Japan and planted at Pearl Harbor, Kaneohe Bay, and Waialae Bay, Oahu, Hawaii (Brock, 1960) where they became well established. Open harvesting began in 1965, but over-collecting caused such a population decline that all harvesting was officially stopped in 1969 (Yap, 1977). About 3000 to 5000 very small clams were sent to Fiji in 1971 from California along with a shipment of seed oysters (Glude, 1972). They arrived in excellent condition and were placed in trays at Cave Island in Bay of Islands near Suva. The present status of these clams is unknown (Andrews, 1985). Known as 'palourde' in France, individuals were transported to French Polynesia in 1980 (AQUACOP, 1982). Initial results appear good; they attained commercial size in less than a year.

Another Japanese clam, *Cytherea meretrix*, was introduced to Hawaii from Japan in 1929 when some 10 gallons were planted at Kaneohe Bay and Kalihi, Oahu. In 1939, a second shipment of 20,000 young individuals was planted at Kaneohe Bay (Edmondson and Wilson, 1940; Brock, 1960). Introduction of the Pismo clam *Tivela stultorum* to Hawaii in 1927 and 1928 was unsuccessful (Brock, 1960).

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